Proton Improvement Plan

Bob Zwaska

September 9, 2013

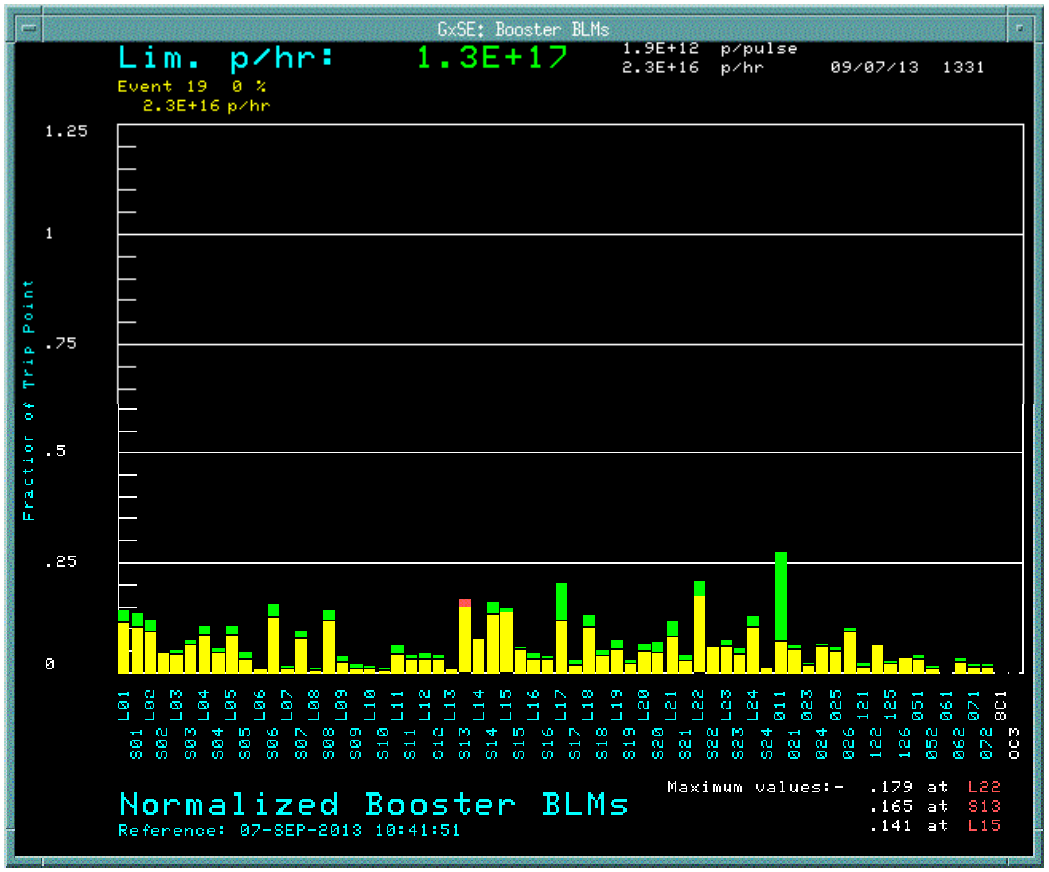
All-Experimenters Meeting

Basics

- Linac and Booster are now running
  - Being tuned for HEP
  - Some PIP improvements being realized
- Major PIP work continues
  - Preparing major items for future downtimes / shutdowns
    - Cavities, vacuum, transformers, power supplies…
  - Studies in Linac & Booster
- Balancing time:
  - No longer have to compete with shutdown for resources
  - Now have to compete with operations

Operating Status

- Booster is providing beam for NuMI. Typical numbers:
  - 3 Hz beam
  - ~ 2.5e12 protons / pulse
  - ~ 2.5e15 protons / hour
    - Present loss levels would accommodate > 6 x throughput
- Study periods have occasionally higher beam rates and intensities:
  - NTF (Linac)
  - Booster Studies
- Limited mostly by Main Injector
  - Lower rep rate because there is no slip stacking
  - Lower intensity until MI conditions



Linac Items

- Linac Hatch installed
  - Allow removal and installation of material into lower-level
  - Chief need is to put in new house-power transformer
    - Next shutdown
- Progress on LEL Power supplies and amplifiers
  - Test cells of Marx generator for high-current, high-voltage pulses
  - Plans for klystron replacements of amplifier tubes
    - Prototype in the works

Cavity Refurbishment

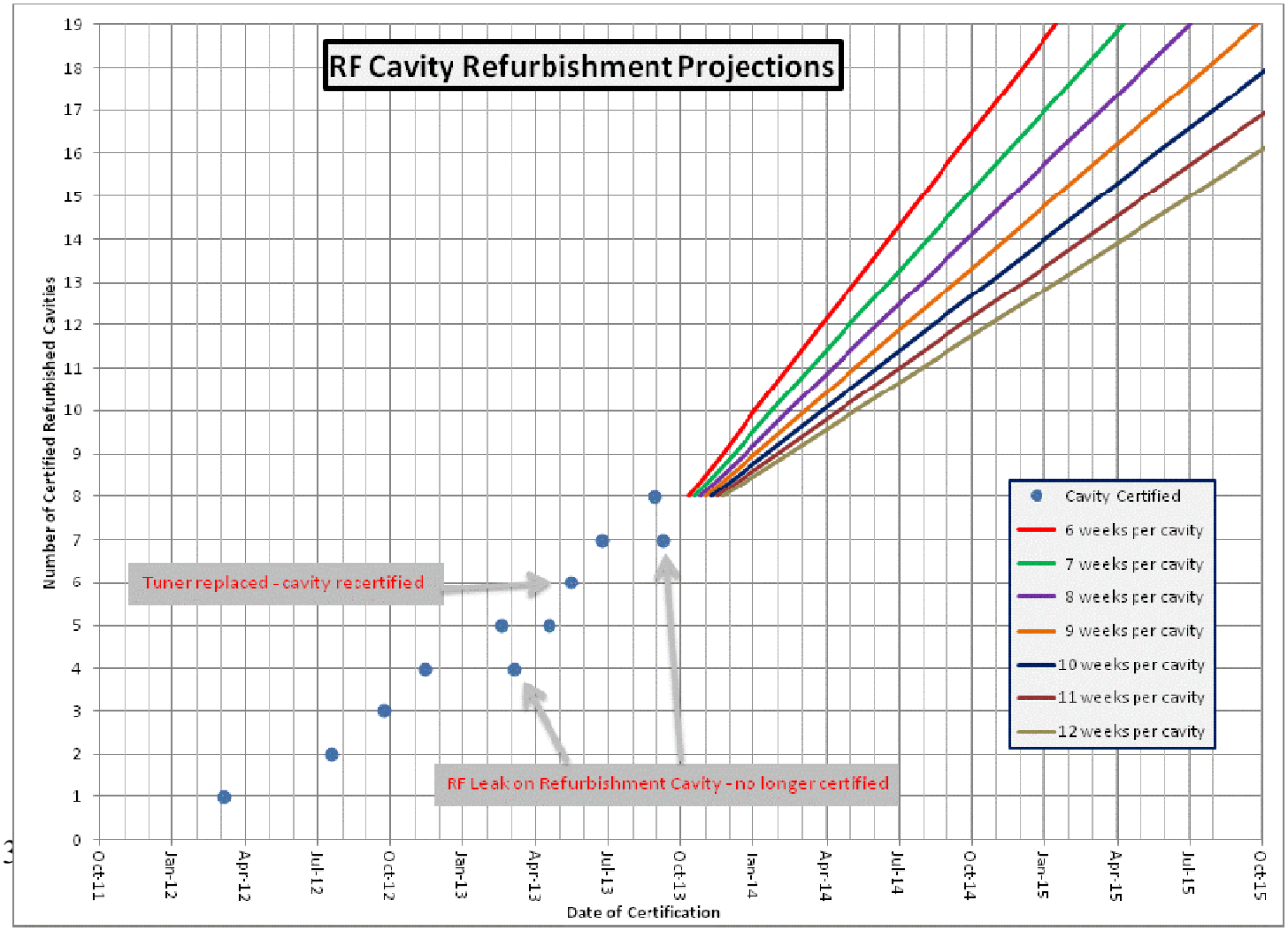
- Refurbishment is the limiting task in getting the Booster to 15 Hz
- Booster has 17/19 cavities in place with two out for refurbishment
  - This will continue throughout the next few years
- Next refurbished cavity to be installed this week
  - Cavity to be removed was the first-refurbished cavity which is leaking RF
  - This will continue throughout the next few years
- PIP anticipates more technicians now that the shutdown is over
  - These persons have not become available yet, even though the machines are operating now
- Also need to build new tuners with new ferrites
  - Issues with ferrite vendors and designs

Cavity (RF17) preparing to repair flanges

Cones and new cooling loops

Refurbishment Projections

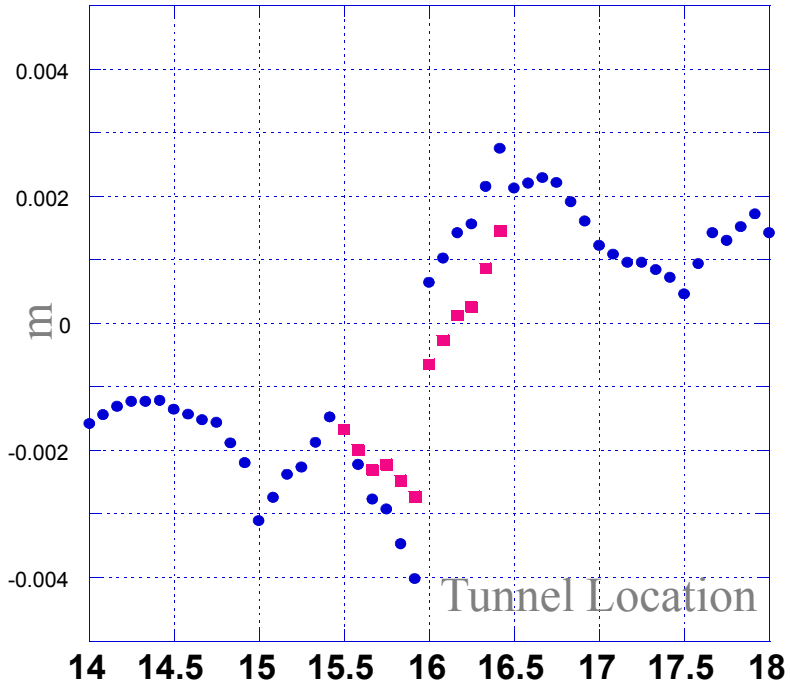
- Have had to rework some of the first-refurbished cavities
  - Process is improving – hopefully accelerating
  - Expect more perturbation as operations exercises cavities to higher rates

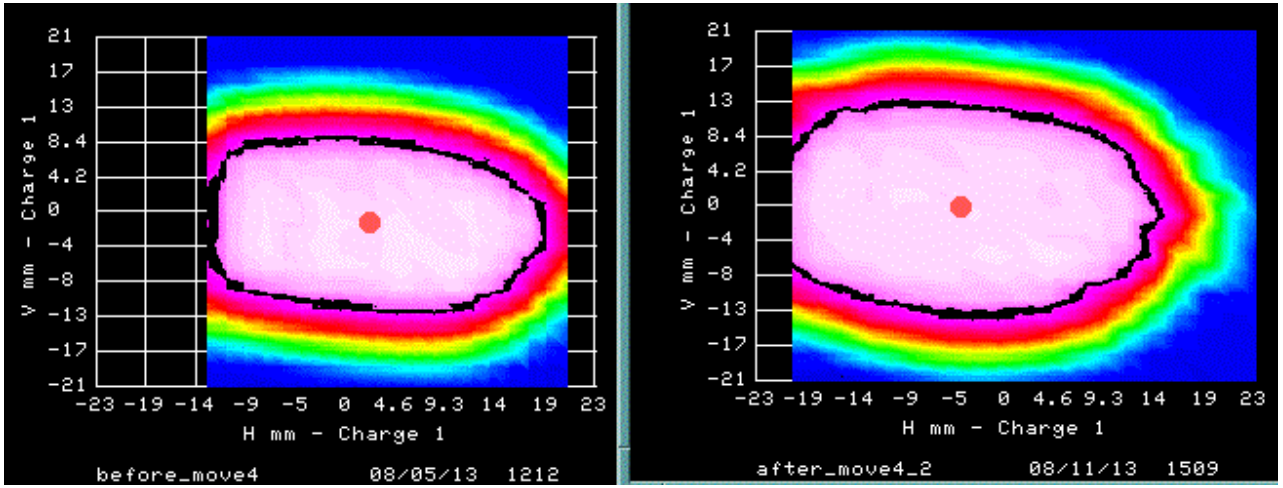


Loss reduction: Booster Aperture

- Magnet moves
- Scans

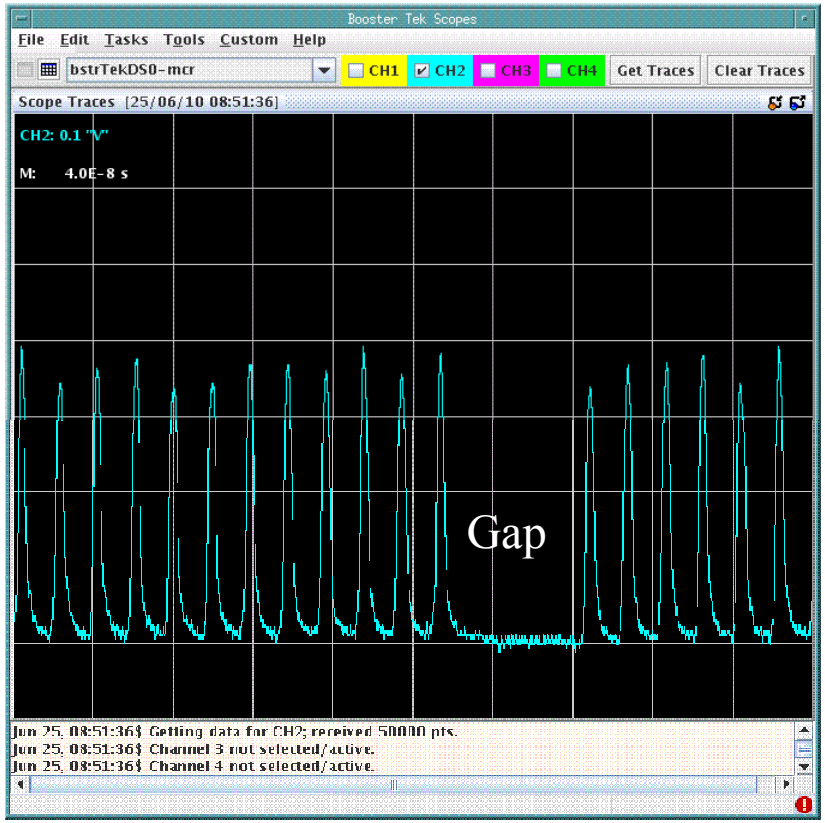
- Location: Long 16 Vertical Move
- Fourth magnet move
- Ready for a fifth
- Plan several more as time allows





Loss Control: Booster Notching

- A “notch” of beam is removed from the Booster near injection to allow the risetime of the extraction
- With the previous scheme, at 15 Hz we would be putting 300 W of losses into the Booster from the notch alone
  - ➢ This loss was localized in a few gradient magnets
- PIP has a 3-stage approach to eliminating the losses from the notch
  1. Modify the notcher arrangement in the Booster
     - Relocated loss into a dump
  2. Cog with the corrector magnets instead of RF phasing
     - Under test now
  3. Make most of the notch in the Linac
     - Loss at 750 keV instead

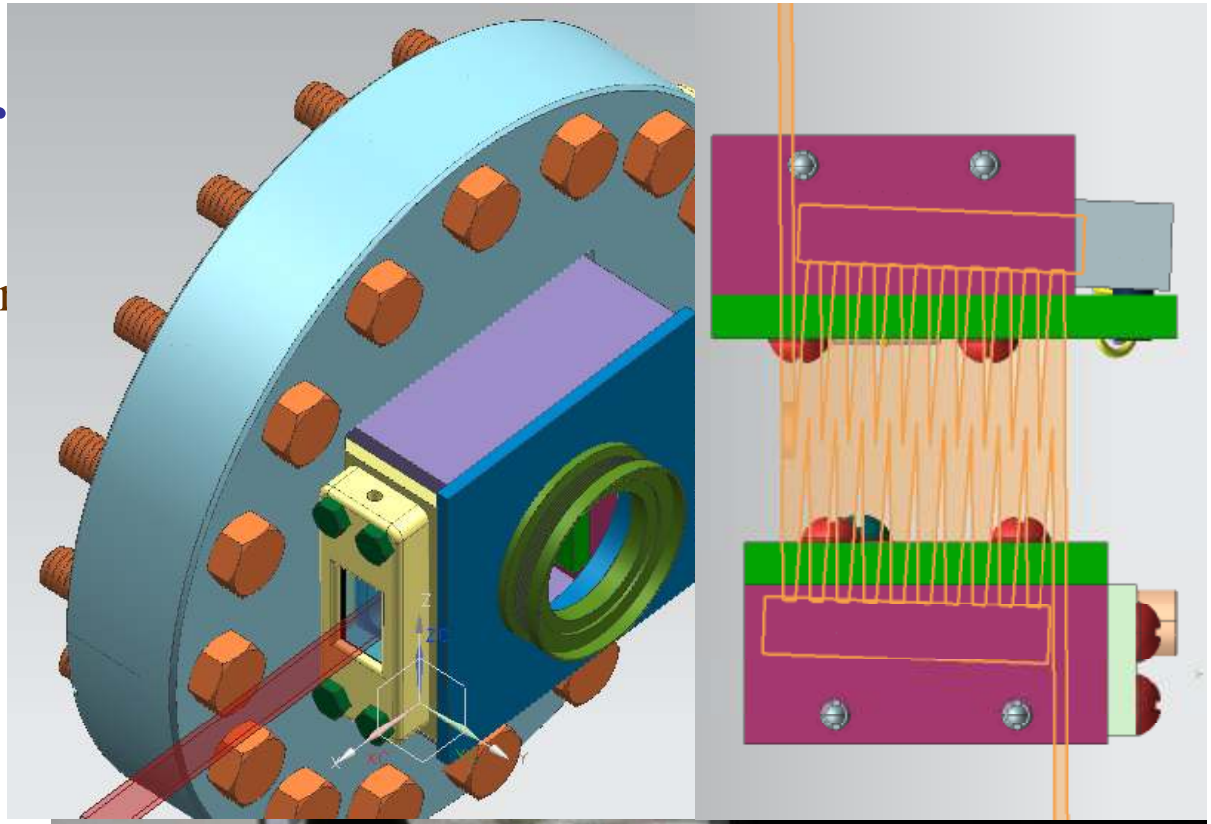


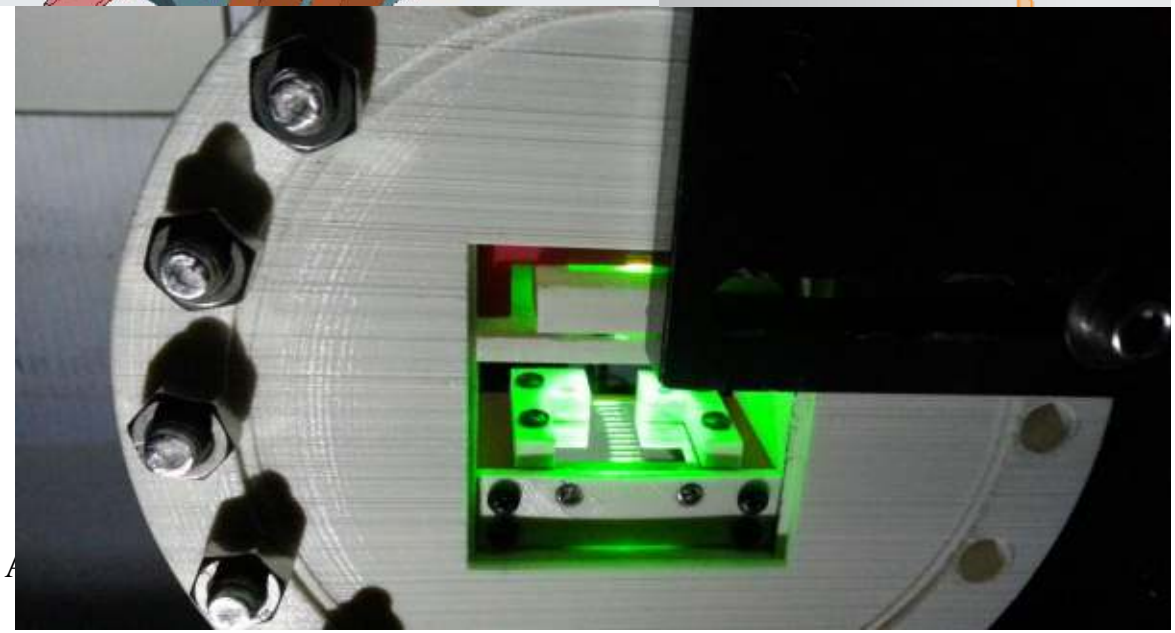
New Absorber & Kickers

- Relocate notch location from a series of kickers into a well-designed dump
  - Old extraction area to Main Ring
- Capable of absorbing 300 W of notching
  - Booster loss budget is 525 W
- New notcher has been operating since startup this year
- Future improvements: shorter kickers for cleaner pulses

Laser Notcher

- Neutralize a portion of the Linac beam with a pulsed laser
  - Remove the majority of the loss from the Booster entirely
- Prototype of the laser front-end is operating
  - Atypical laser
    - Multiple timescales
    - High-pulse power
    - Moderate average power (few W)
  - Final gain stages being specified
- Prototype of interaction region built with 3-D printer
  - Looking into collaborative production and testing of the final chamber





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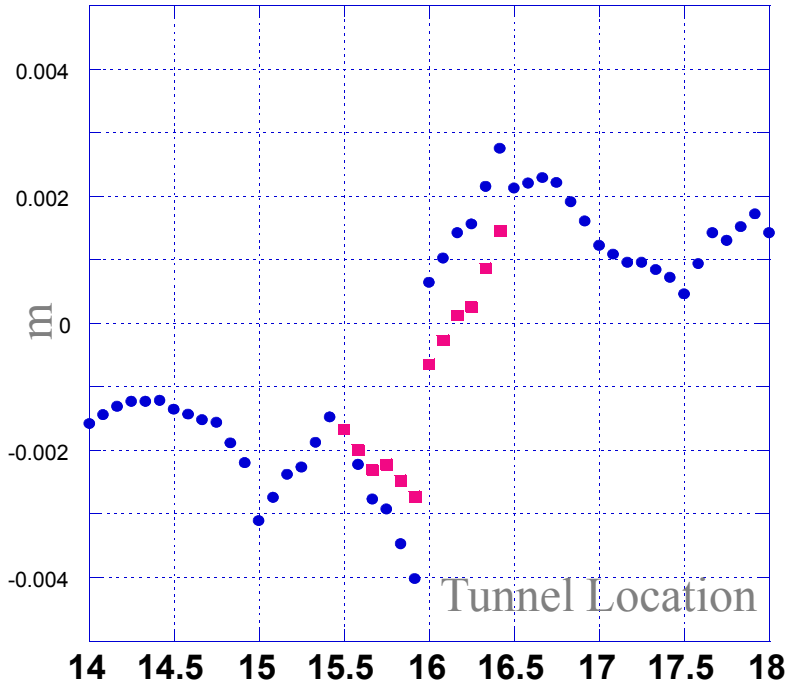

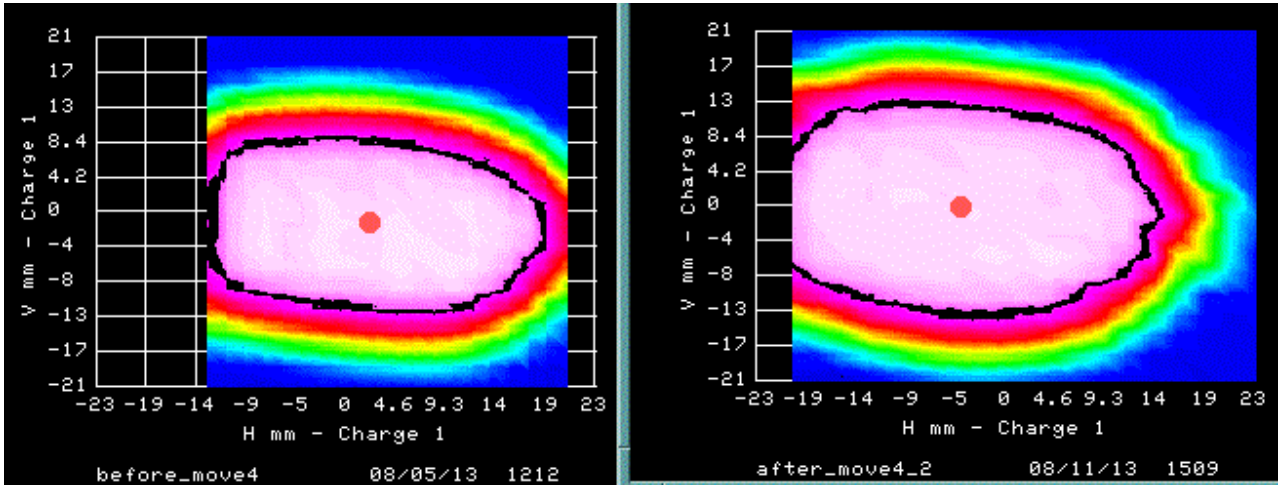

Summary

- Proton Source is operating
  - Operations are at a moderate level of intensity with low losses
  - Some PIP improvements in place
  - High-power beam awaits MI conditioning –or – Recycler slip stacking – or – Booster Neutrino Beam
- Work continues alongside operations
  - Refurbishment is the limiter to reaching 15 Hz operation
    - Critically need labor to support the refurbishment effort and coordination of various groups (also operations again)
    - Other systems also need replacement – but not time-critical yet
  - Studies in progress to reduce and control losses
  - Major upgrades still in the work to ensure long-term viability of the Proton Source

Proton Improvement Plan

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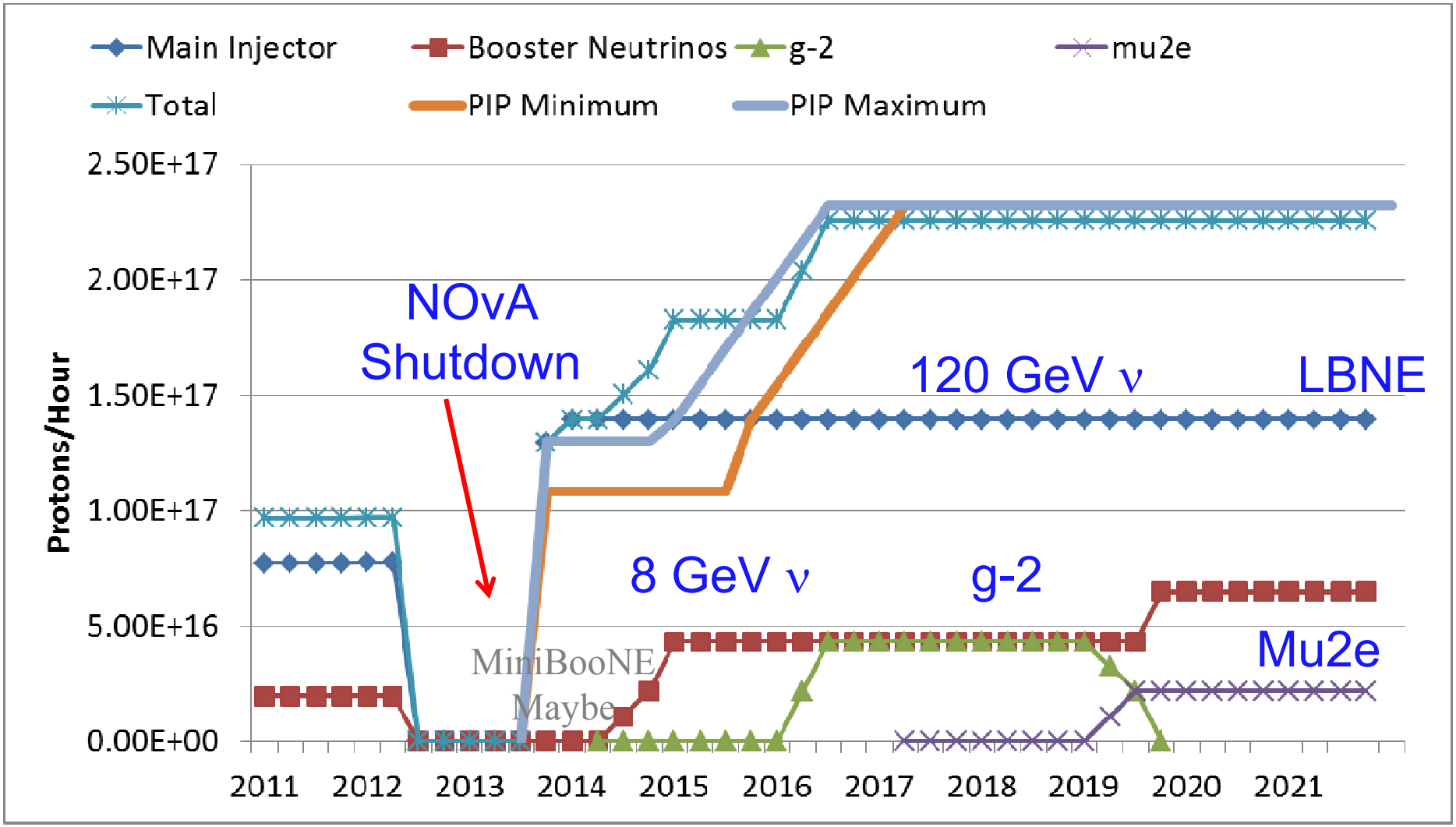
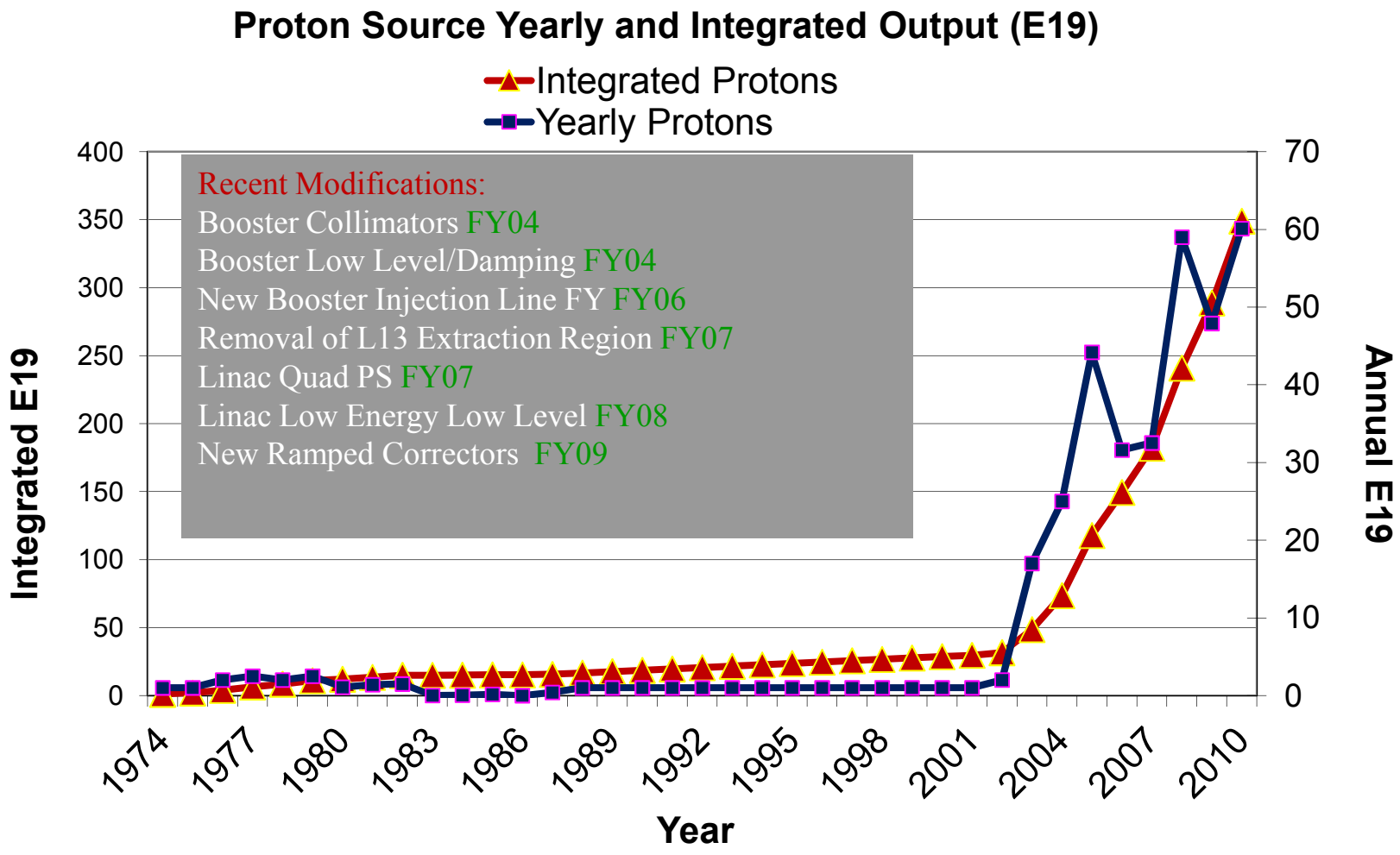
All-Experimenters Meeting

Proton Improvement Plan Projection



Booster - Historical Performance



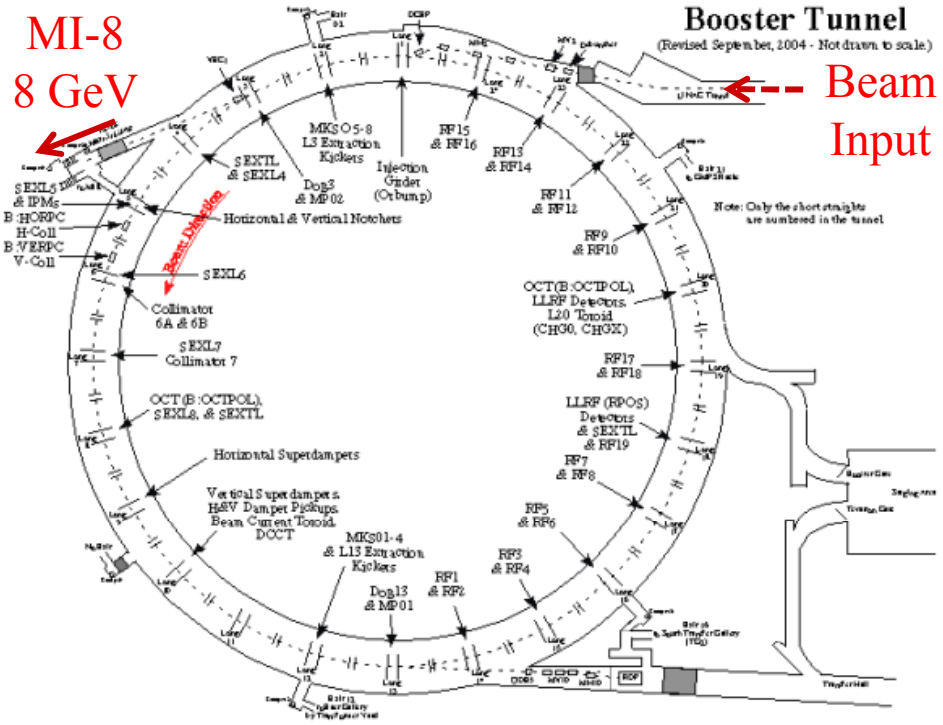
Goals for the Proton Improvement Plan

- The ***Proton Improvement Plan*** should enable Linac/Booster operation capable of
  - Delivering 2.25E17 protons/hour (at 15 Hz) in 2016

  while
  - Maintaining Linac/Booster availability > 85%, and
  - Maintaining residual activation at acceptable levels

  and also ensuring a useful operating life of the proton source through 2025.
- The scope of the ***Proton Improvement Plan*** includes
  - Upgrading (or replacing) components to increase the Booster repetition rate
  - Replacing components that have (or will have) poor reliability
  - Replacing components that are (or will soon become) obsolete
  - Implementing improvements or operational changes to reduce beam loss
  - Studying beam dynamics to diagnose performance limitations
- Several significant activities are well underway

Booster



- 15 Hz Synchrotron
- Resonant Gradient Magnets
- Tunable RF Cavities
- 400 MeV to 8 GeV

Proton Improvement Plan Development

- Proton Task Force (PTF) FY10
  - Initial effort to understand Proton Source Concerns
  - Focused on reliability and modernization
- Proton Improvement Plan Workshop – Jan 2011
  - Review of PTF
  - Review of additional issues associated with flux
- Management Structure – 2011 Summer
  - Established project team and ground rules
- Planning Structure – 2011 Fall
  - Managers established for all subprojects
- Resource Loaded Schedule 2011 Winter
  - Bottoms-up estimation of all subprojects
- Detailed Project Organization – 2012 January
  - Project Management Plan
  - Project Design handbook
  - Accounting codes & signature authority

References

- A Plan for Delivery of 8-GeV Protons through 2025, Beams-doc-3781, http://beamdocs.fnal.gov/ADpublic/DocDB/ShowDocument?docid=3781

- Proton Source Task Force Report, Beams-doc-3660, http://beamdocs.fnal.gov/ADpublic/DocDB/ShowDocument?docid=3660

- Proton Source December 2010 Workshop, http://beamdocs.fnal.gov/ADpublic/DocDB/DisplayMeeting?conferenceid=114

- PIP Home Page: http://www-ad.fnal.gov/proton/PIP/PIP_index.html

Booster Losses

- Losses at injection
  - Poorly captured beam
- Notch creation
  - Gap for extraction
  - Created with a kicker
  - Lost in gradient magnet
- Slow losses at high-energy
  - Optics issues
  - RF variation
- Transition
  - Occasionally significant, but can usually be tuned away

Path to Higher Proton Throughput

- Loss reduction
  - Lower linac emittance
    - RFQ & linac lattice improvements
  - Apertures & alignment
    - Comprehensive survey of apertures
    - Alignment where necessary (including within girders)
    - Opening apertures where possible
  - Optics adjustment
    - Comprehensive survey of lattice and coupling
    - Control of tunes and chromaticity
    - Automated orbit and optics smoothing
  - RF improvements
    - Increased voltage from amplifiers
    - Cavity modification/replacements
  - Instabilities
    - Dampers
  - Injection painting
- Orbit Control
  - Magnetic Cogging
    - Prerequisite for other work
- Loss Control
  - Rework of notching in Booster
    - Perform earlier in cycle
    - New notch kickers and absorber
    - Exploration of full or partial notching in Linac
  - Collimation system
    - Operate as true, two-stage system
    - Run beam near primary scatterer
    - Optimize primary scatter thickness
  - Adjust radiation shielding where advantageous